Combustion and performance of DI diesel engines using biodiesel of kemiri sunan (*Reutealis Trisperma Airy Shaw*) as a alternative fuels

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ABSTRACT

Petroleum reserves as a fuel energy source in Indonesia are expected to be exhausted in 23 years if there is no alternative of fuels. Along with the government's program of energy security, it encourages researchers to look for potential alternative fuels sources instead of fossil fuels. One of the renewable energy that is currently heavily studied is biodiesel. In this paper describes one of the biodiesel that is kemiri sunan (*Reutealis Trisperma Airy Shaw*). Kemiri sunan is a conservation plant that grows in the ecosystem argo area with high oil content. Kemiri sunan biodiesel test was conducted to find out the combustion result and its performance. The tests were conducted on direct injection diesel engines with mixed fuel compositions between biodiesel and diesel fuel produced by Pertamina (B15 and B20). Then kemiri sunan biodiesel test results will be compared with diesel fuel produced by Pertamina itself. Parameters taken include pressure, heat release, ignition delay, power, torque, break mean effective pressure, specific of fuel consumption, and thermal efficiency. *The results show that kemiri sunan biodiesel has potential as a alternative fuels*.

Keywords: Kemiri Sunan Biodiesel; Combustion, Performance

I. INTRODUCTION

A. *Biodiesel Overview*

Diesel engines, fuels and renewable energy are topics that prioritized by many parties, especially researchers. This is to provide recommendations to government about renewable diesel engine technology. With the characteristics of efficiency, durability and high reliability, making diesel engines can be applied in various fields [1]. However, the fuel of this diesel engine still comes from a conventional source (fossil). Many countries experiencing the problem of shortage of fuel sources are no exception Indonesia. Whereas the country's need for fuel is enormous. Non-renewable fuels are very limited in existence and over time will decrease their source capacity [2].

Biodiesel is one of energy sources that being studied and developed. Using biodiesel as fuel is one of the efforts from researchers and Indonesian government to reduce dependence by using fossil sources. This source is composed of mono alkyl esters of fatty acids derived from renewable vegetable oils or animal fats. Essentially vegetable oils and animal fats are long-chain saturated chain triglycerides and unsaturated fatty acids.

Theoretically, the composition of vegetable oils or animal fats can be directly applied to diesel engines, but from direct use will cause some problems such as pumping, gumming, atomization, injector fouling, carbon deposit until component acceleration becomes worn out [3]. Therefore there is a standard that regulates biodiesel fuel, which aims to set a minimum limit of the fuel characteristics of vegetable oils or animal fats can be used in diesel engines.This standards have been established and developed in various around the world such as American Society for Testing and Materials (ASTM) International as fuel that meetting the requirements of ASTM, Europan Standard (EN) [2], International Organization for Standardization (ISO) [3], Brazil, South Africa, Australia and elsewhere.

Biodiesel is a lot of attention to researchers because it has advantages and benefits. One of the advantages of properties such as cetane number, flash point, sulfur content, non-toxic and of course the resulting gas emissions not far from diesel fuel. In addition, biodiesel is also capable of being mixed with diesel fuel in different ratio compositions without requiring modifications to the engine in testing [4]. Other advantages can be reviewed environmental aspects. Using biodiesel gives consequences about emissions from gas produced. The gas emissions consist of Hydrocarbons (HC), Nitrogen Oxides (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Particulate Matter (PM). Where gas emissions could affect air pollution, especially the ozone layer and affect human health [5]. Some researches have concluded that the use of biodiesel is able to reduce gas emissions from those produced by diesel fuel, such as HC, CO, and PM. However, the NO content produced by biodiesel fuel is greater than that of diesel fuel. This of course will also have an impact on the environment of human health, acid rain to the acidity of water sources [6].

There have been studies conducted both by researchers and students throughout Indonesia related to fuels development from vegetable oils and animal fats. Some of the products that have been studied have even been applied, such soybean oil (*Glycine Max*), jatropha oil (*Jatropha Curcas*), rapeseed oil (*Brassica Napus*), palm oil (*Elaeis Guineensis*), sunflower oil (*Helianthus Annuus*), corn oil (*Zea Mays*), peanut oil (*Arachis Hypogaea*), and cotton oil (*Gossypium Spp.*) [2][7]. With a variety of potential sources of fuel has placed Indonesia in second place. The rankings of fuel producers from vegetable oils and animal fats can be seen in **Table I** above.

TABLE I. TOP 10 COUNTRIES IN BIODIESEL POTENTIAL SOURCE

Ranking	Country	Biodiesel potential (ML)	Production ($/L)
1	Malaysia	14,540	0.53
2	Indonesia	7,595	0.49
3	Argentina	5,255	0.62
4	USA	3,212	0.70
5	Brazil	2,567	0.62
6	Netherlands	2,496	0.75
7	Germany	2,024	0.79
8	Philiphines	1,234	0.53
9	Belgium	1,213	0.78
10	Spain	1,073	1.71

Sources (2012, Atabani)

In this research has been discussed about one of Indonesia's biodiesel that is kemiri sunan. Kemiri sunan plants (*Reutealis Trisperma Airy Shaw*) is one of the plants that potential to become biodiesel. This is because it contains oil with a yield of about 40-60%. This plant is developed in various cities on Java Island has even spread to other islands such as Sumatra, Nusa Tenggara, until Borneo. The rapid development of kemiri sunan is not only potential as biodiesel but also as an argo ecosystem, which is capable of being used as a conservation crop [8][9].

B. Combustion & Performance of Diesel Engines

The development and use of biodiesel fuel worldwide is one of the efforts undertaken to reduce the emission gas emitted [10]. Gas emission levels resulting from diesel engines are certainly influenced by the quality of these fuels. Fuel quality can be seen from its characteristics such as flash point, pour point, cetane number, density, viscosity, low heating value and many more [11]. Each fuel characteristic of course provides combustion results and different performance on diesel engines.

Theoretically, analysis of diesel engine combustion process can be seen from several aspects such as ignition delay, rate of pressure rise, peak pressure and heat release [12]. Combustion process is the process of burning between fuel injected with turbulent air entering and becoming one inside the engine combustion chamber. The process produces high pressure and temperature up to a certain point of fire occurrence and spreads until a complete combustion process occurs. But in the process it is not directly burning but takes time to reach the process called the ignition delay [13].

Igntion delay is the length of time required when starting fuel injection (*Start of Injection*) until the first combustion occurs (*Start of Combustion*). Where the results are shown in how much degree is taken for process of ignition to explosion. The occurrence of ignition delay is due to process of vaporizing between fuel and air that forms heat reaction and will burn when it has reached the upper limit or critical point of both the mixture. Whether or not the time it takes for the fuel to burn immediately is influenced by fuel characteristics such as the cetane number that serves as an indicator the burned ignition will ignite by itself (autoignites). In addition, this process is important indicator of combustion process because it will affect the quantity of fuel injected into combustion chamber diesel engine. The longer ignition delay the more fuel is injected, and when the combustion process occurs potentially the occurrence of diesel knock.

Pressure aspect is divided into two stages namely rate of pressure rise and peak pressure. Theoretically the pressure in the combustion chamber is influenced by the quality of fuels such as density, viscosity and low heating value [12][13] . The definition of rate of pressure rise is pressure average that generated from combustion between fuel and air. Then the definition of peak pressure is the highest pressure level of pressure rise. From these two reviews when it has great value it can be concluded that the amount of fuel injected is more than any other fuel. Pressure generated from combustion process is one of the reaction of energy changes between the fuel that changes in addition to being heat. Energy changes to heat in the combustion chamber can be analyzed from heat release. This indicator serves to provide information related to combustion process associated with pressure and ignition delay.

From the combustion process diesel engine then produced work that can be analyzed from the performance. Definition of performance is the criterion value of engine to assess quality of fuel used. Diesel engines performance is consists of several indicators such as power, torque, BTE, BMEP and SFC [12]. The indicators of performance testing are interconnected. Power is the most important indicator of performance testing, where has the intent as the characteristics of the work produced by diesel engines. The units of power are kN. Then torque is an indicator that has the meaning of rotation force generated per one rotation of diesel engine. Torque has a unit Nm. Brake mean effective pressure is a generated force magnitude between torque and volume of fuel chamber. Specific fuel of

TABLE II. ENGINE SPECIFICATION

Model	**Specification**
Diesel Engine	Yanmar TF-85
Engine Type	DI, 4-stroke, diesel engine, natural aspirated, water cooled
Bore x stroke (mm)	85 x 87
Displacement (cm3)	493 cm
Compression Ratio	18:1
No. Of Cylinder	1
Maximum Power (kW)	5.2 kW/2200 rpm

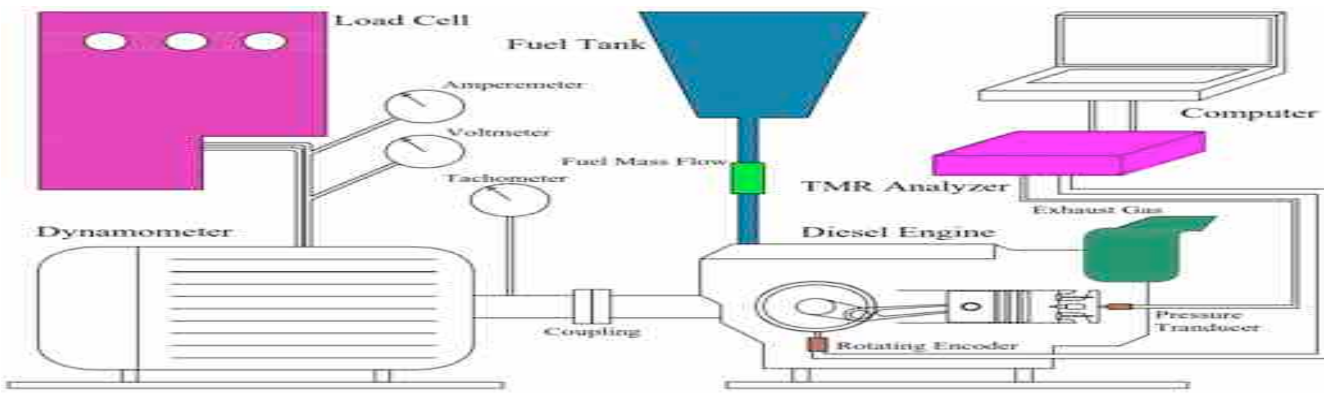


Figure 1. Engine Setup

consumption is the amount of fuel (mass flow rate) that is converted into work in units of time [5]. The value of large or small power, torque, fuel consumption and thermal efficiency generated by a diesel engine is certainly influenced by some indicators of fuel properties such as lower heating value, density and viscosity.

Because fuel properties can provide a very significant impact, especially when the combustion process in diesel engines take place [12].

This research is an analysis of combustion and performance of biodiesel that is kemiri sunan. Where in this study will be tested based on several indicators that will be described in the next chapter. It is intended to find out how much the quality of the fuel to be applied to diesel engines.

V. METHODS

A. Engine Setup

In this research, the method that be used is experiment. Before test performance, a preparation such as engine setup that will be described in **Figure I**. It also described the engine specifications that can be seen in **Table II**. This test is done on a laboratory scale so that the results obtained still need further development. The engine setup in **Figure I** is an arrangement consisting of a diesel engine with the addition of an outside fuel tank along with its fuel filter. This is done as a form of supervision of fuel flow velocity. Diesel engine is connected with dynamometer and load share to find out how much power is generated. The presence of an ampere meter device and a volt meter to determine voltage and current strength generated by diesel engine. So from this series of engine setup will produce the form of performance of both fuels.

B. Fuel Properties

After engine setup process is done, next step is knowing a fuel properties of kemiri sunan biodiesel. The process of making both biodiesel both use transesterification process [14]. From these fuel properties will be able to see whether two biodiesels meet predetermined standards (using ASTM and EN ISO). With results of fuel properties that meet standards then combustion and performance test of kemiri sunan biodiesel can be done.

TABLE III. FUEL PROPERTIES OF KEMIRI SUNAN BIODIESEL

Parameter	**Test Method**	**Limits**	**Kemiri Sunan Biodiesel**
Flash Point (^oC)	ASTM D93	Min 55	188
Pour Point (^oC)	ASTM D664	Max 18	4
Density at 15^oC (kg/m^3)	EN ISO 12185	800 – 890	880
Kinematic Viscosity at 40^oC (mm^2/s)	ASTM D445	2.3 – 6.00	8.23
Water Content (%)	ASTM D1796	Min 0.05	0.11
Lower Heating Value (MJ/kg)	ASTM D240	Max 42.934	42.379

C. Engine Performance Variables

After engine setup and fuel properties done, determination of variables for testing performance. First variable is variable fuel, biodiesel mixed with diesel fuel (Pertamina Dex) owned by Pertamina [15]. The variables of the fuel is B15, B20 and B100 (diesel fuel). Second variable determination is RPM and load variable, diesel engine that used in test is rotated at RPM 1800 and RPM 2200. Then for the load variable used is 20%, 40%, 60%, 80% and 100%. From the determination of the variables above then the next is the data retrieval that will be discussed in the next chapter.

D. Combustion & Performance Test

Engine performance test is performed after both variable fuel and load are determined. The indicators to be taken the results are divided into two, data collection from combustion process and performance test. Data from combustion process consist of pressure, heat release and ignition delay [16]. Data from performance test such as power, torque, brake mean effective pressure, themal efficiency and specific of fuel consumption. From these two indicators will be analyzed and compared between biodiesel candle holder with diesel fuel (Pertamina Dex) by Pertamina.

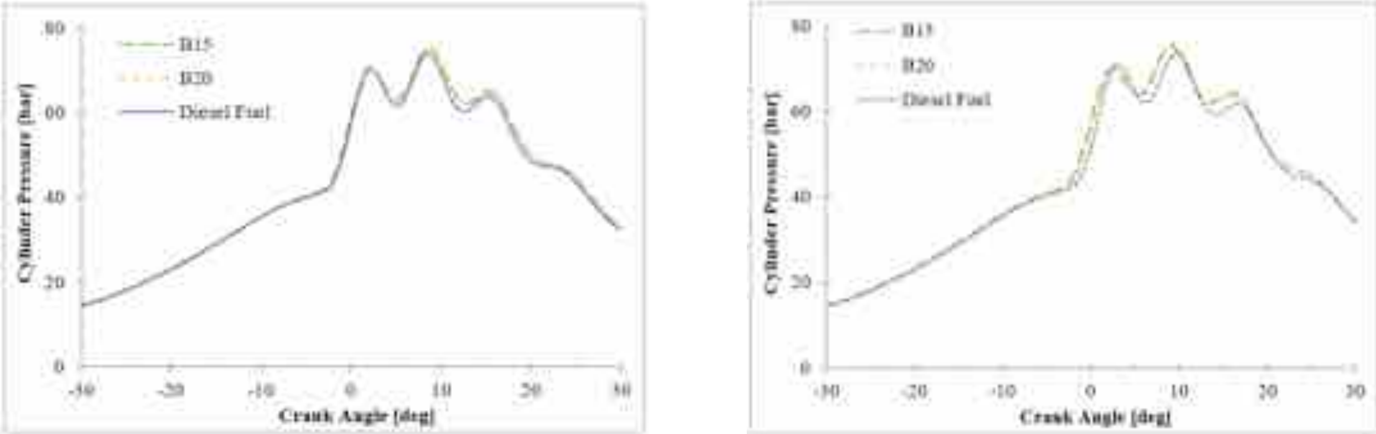
VI. RESULT & DISCUSSION

A. Kemiri Sunan Biodiesel Properties Result

The step of making kemiri sunan into this biodiesel using transesterification method. The results of laboratory testing can be seen in **Table III** above. Characteristics that have been tested include density at 15^oC, viscosity at 40^oC, flash point, pour point, water content, and lower heating value. From several indicators that have been tested, there are 4 indicators that match the criteria of biodiesel which are flash point, pour point, density at 15^oC and lower heating value [2]. Based on the standard used for reference of these indicators, there is one indicator that does not meet the standard that is kinematic viscosity at 40^oC. This can be due to lack of perfect when the process of making from raw materials into biodiesel.

B. Combustion Test Results

Combustion process results can be seen in some pictures below. **Figure 2** above shows the result of pressure from combustion chamber using three fuels that is kemiri sunan biodiesel (B15, B20) and diesel fuel. **Figure 2a** is a condition where pressure occurs at 1800 rpm rotation and full load. And **Figure 2b** is a condition in which pressure occurs at 2200 rpm and full load. In both diagrams, fuel that be able to reach premix combustion is kemiri sunan biodiesel B15; B20 then diesel fuel.



(a) (b)

Figure 2. Cylinder pressure diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load

(a) (b)

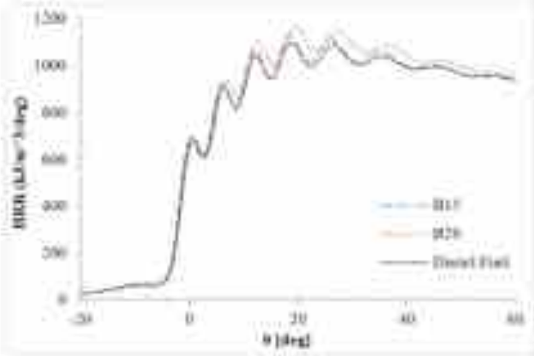
Figure 3. Ignition delay diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load

At full engine speed of 1800 rpm, the pressure on premix and stage combustion of B15 is 70.10 bar at 0^0 and 76.39 bar at 6^0. The pressure on premix and stage combustion of B20 is 68.10 bar at 1^0 and 74.37 bar at 6.5^0. Pressure on premix and stage combustion of diesel fuel is 69.73 bar at 0.5^0 and 74.32 bar at 6.5^0. Furthermore, the conditions on the engine speed 2200 rpm with full load. The pressure on premix and stage combustion of B15 is 69.82 bar at 2.5^0 and 75.36 bar at 9^0. The pressure on premix and stage combustion of B20 is 70.65 bar at 2.5^0 and 75.65 bar at 9.5^0. Pressure on premix and stage combustion of diesel fuel is 70.82 bar at 3^0 and 73.33 bar at 10^0. This is indicate influence of mixed characteristics of biodiesel fuel and diesel fuel. However, there is one condition where the premix combustion of B20 fuel is well after B15 and diesel fuel occurs. This could be due to the influence of fuel mixture for low rpm conditions having long burning delay so as to produce pressure that is also longer than the two fuels above. These characteristics affect energy process that changes from chemical to heat and kinetic.

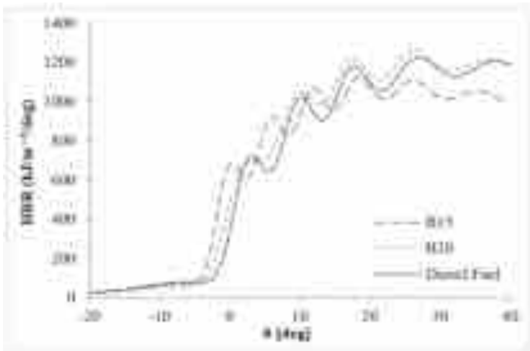
Theoretically, the fuel and air that entering chamber under heterogeneous conditions give non premixed combustion, due to that conditions have not become homogeneous. However, premixed conditions can be obtained if the acceleration of mixing of fuel with air so quickly to provide homogeneous [17][11]. Fuel conditions that are not homogeneous in a timely manner certainly affect the combustion process such as increased ignition delay, temperature, pressure in cylinder and peak HRR [16]. Similar results obtained from the research [18] where using biodiesel fuel produce higher peak pressure when compared with diesel fuel. A non-premix condition is not affected by a change in the ratio of air fuel. However, increased concentration of fuel mixture that will affect energy changes when premix combustion. So as much as possible in the combustion process required fuel that can form a homogeneous mixture because it will provide the effect of optimal combustion efficiency and high peak pressure on the cylinder.

The pressure occurring in combustion chamber is of course not only influenced by fuel characteristics but also influenced by length of period between injection, mixing and combustion from fuel and air. This case is called ignition delay. In theory, this process is influenced by fuel and engine design. The result of combustion process that is ignition delay from kemiri sunan biodiesel and diesel fuel can be seen in **Figure 3** above. In **Figure 3a** is result of ignition delay from engine speed 1800 rpm and full load, and in **Figure 3b** is result of ignition delay from engine speed 2200 rpm and full load. It can be seen in **Figure 3a** that shorter delay is achieved by diesel fuel and longer delay is achieved by B15. That conditions is inversely to Figure 3b, where these conditions the fastest delay is achieved by diesel fuel, then B15 and last is B20. This is evidenced by the study of [19] which shows that the influence of content from fuel mixture between kemiri sunan biodiesel and diesel fuel (B15, B20). Both of biodiesel characteristics that is viscosity and density contents cause chemical process during combustion takes a long time. So in injection process resulted in delay time is longer than diesel fuel. Combustion process is a combination of interconnected processes. Such as cylinder pressure, ignition delay and heat release rate. This discussion discusses heat energy generated by combustion in combustion chamber of a diesel engine or so-called heat release rate. Combustion process is a change between chemical energy into kinetic and heat. Chemical energy derived from fuel and mixed with air and very high pressure causes the release of energy into heat and explosion. So energy generated from explosion produces kinetic energy [11].

The final analysis of the combustion process can be seen in **Figure 4** below, which is a diagram for heat release rate (HRR) of kemiri sunan biodiesel and diesel fuel. In **Figure 4a** it is a condition where HRR occurs at 1800 rpm and is full. **Figure 4b** is a condition in which HRR occurs at 2200 rpm and full load. From these two diagrams can be seen the start of combustion that is early fuel kemiri sunan biodiesel B15; B20 then diesel fuel. From which it affects the HRR which is also at the beginning of the position. But there is one condition where the HRR of fuel B20 is far away after B15 and diesel fuel occurs. This could be due to influence of fuel mixture for low rpm conditions having long burning delay resulting in lower HRR.



(a)



(b)

Figure 4. Heat Release Rate diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load

The combustion process resuls of three fuels can be seen that the effect of low HRR caused by the influence of rapid injecting delay and long duration of combustion in the condition of premix combustion and steady combustion. Especially in biodiesel fuel which has lower HRR than diesel fuel. It is because of the influence of the process of mixing the fuel into the air when in the combustion chamber. Conditions that do not produce homogeneous compositions over time will result in longer delays and decreased HRR. This is similar to the study by [20] which uses biodiesel as fuel and produces low premix combustion, longer ignition delay, and lower HRR than diesel fuel.

C. Performance Test Results

The performance of the three fuels tested on the diesel engine has been done. Performance tests that have been conducted consist of power, torque, SFC, BTE, BMEP. The explanation will be explained below. Combustion process that occurs in diesel engines is a process of chemical energy changes to heat. Power and torque which is the result of energy can be seen that the energy produced is almost the same among the three fuels. For the highest top power at 1800 rpm engine speed and full load diesel fuel. Then the highest top power on engine speed 2200 rpm and full load achieved by B20. This is due to influence of each fuel characteristics.

Performance results in terms of fuel consumption can be seen in **Figure 5**. Which of three fuels tested results obtained differed in each condition. In all engine rotation conditions that is 1800 rpm and 2200 rpm with full load, it can be seen that the greatest SCF value is B15 then B20 and diesel fuel. The SCF value to be compared is the curve with the lowest value of each fuel. The initial conditions are 1800 rpm engine speed and full load. The lowest SCF value of B15 is 353.85 g/kWh with a power of 2.05 kW. Then for the lowest SCF value of B20 is 329.4 g/kWh with power of 3.4 kW and the lowest SCF value of diesel fuel is 321.7 g/kWh with power of 3.3 kW. Then the second condition is engine speed 2200 rpm with full load. The lowest SCF value of B15 is 365.10 g/kWh with a power of 4.8 kW, the lowest SCF value of B20 is 340.79 g/kWh with a power of 4.7 kW and the lowest SCF value of diesel fuel is 300.17 g/kWh with a power of 4.9 kW. From the above results, the change in SCF value is of course influenced by the characteristics of fuels such as viscosity, density and lower heating value, where the fuel has different characteristic values.

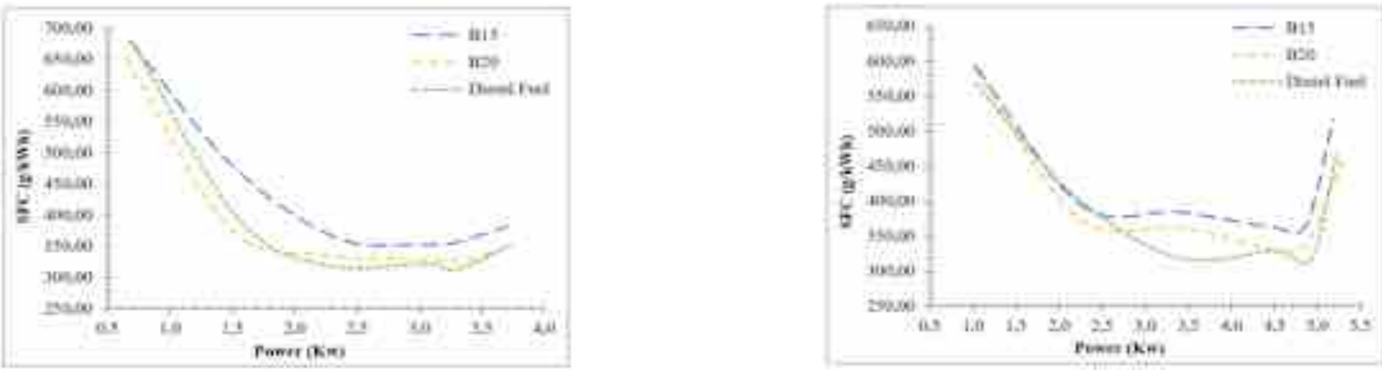
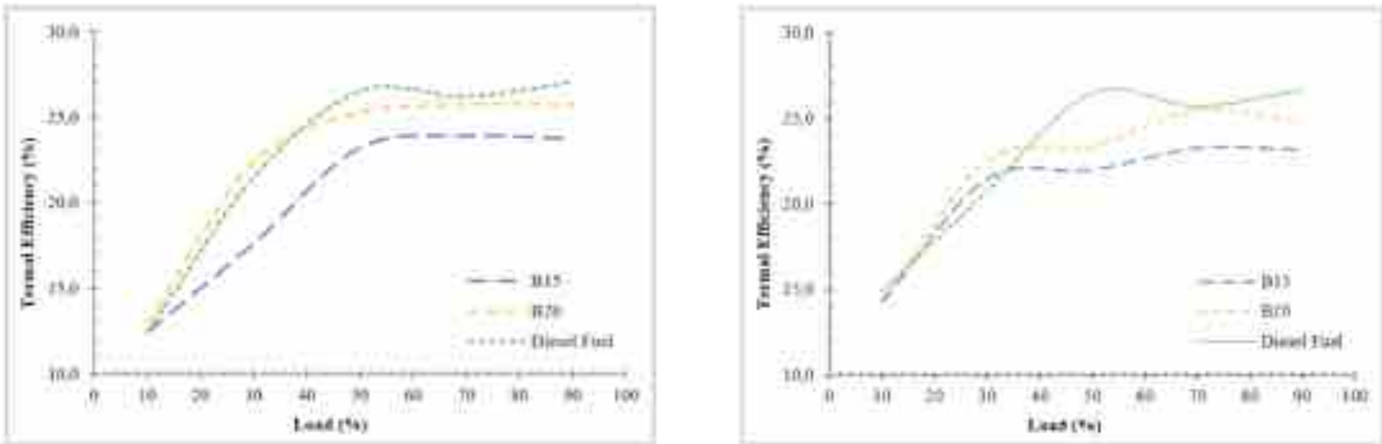


Figure 5. SFC diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load



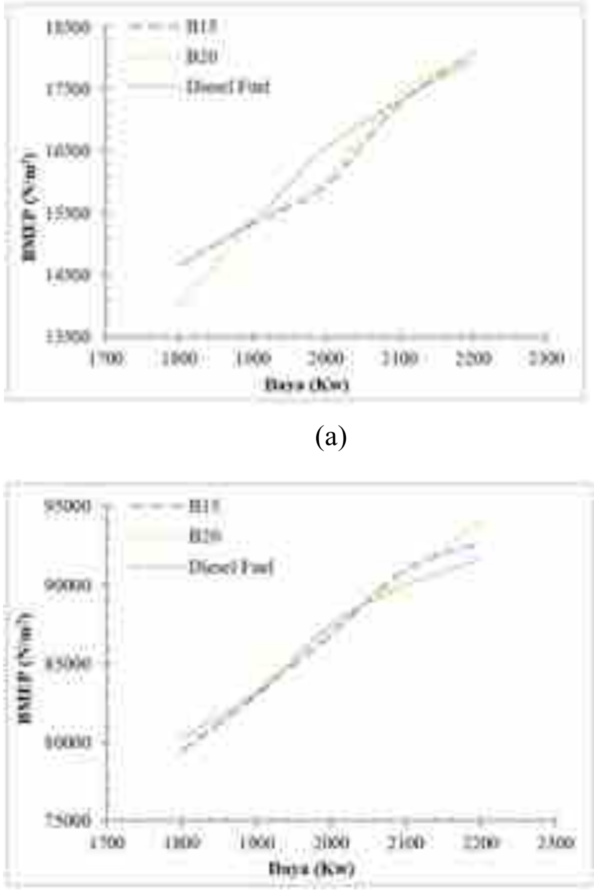
(a) (b)

Figure 6. BTE diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load

Results of this test can be concluded that decreasing SFOC graphs along with increasing the load on diesel engine due to percentage of fuel required to combustion process decreased compared with the percentage of power generated. However, as the load increases towards the highest SFOC increases due to the number of losses generated to achieve the desired power, requiring a large percentage of fuel injected [21].

Next performance test results is brake thermal efficiency (BTE). This test is to find out how much energy efficiency with unit percent. Test results can be seen in **Figure 6**. In both conditions it can be seen that the highest BTE is achieved by diesel fuel fuel, then B20 and last is B15. In the first condition that is 1800 rpm engine speed with full load. The highest BTE value at full load of diesel fuel is 27.01%, B20 value of BTE is 25.73% and B15 value of BTE is 23.93%. While on the second condition is 2200 rpm engine speed with full load. The highest BTE value achieved by diesel fuel is 25.01%, then the value of BTE achieved by B20 is 24.85% and the BTE value achieved by B15 is 23.19%. From test result can be concluded that thermal efficiency has increased or decreased caused by some indicators of fuel properties such as high density and low heating value. Where the impact on energy changes from fuel to burn and heat energy [19].

The last performance test results is brake mean effective pressure (BMEP). This test is to know the magnitude of the force of torque versus volume in fuel chamber. Test results can be seen in **Figure 3b**. In both conditions it can be seen that the highest BMEP is achieved by diesel B20, then B15 and last is diesel fuel. In the first condition that is 1800 rpm engine speed with full load. The highest BMEP value at full load of B20 is 18,033 N/m^2, B15 value of BMEP is 18,075 N/m^2 and diesel fuel value of BMEP is 17,495 N/m^2. While on the second condition is 2200 rpm engine speed with full load. The highest BTE value achieved by B20 is 93,938 N/m^2, then the value of BTE achieved by B15 is 92,700 N/m^2 and the BTE value achieved by diesel fuel is 91,622 N/m^2. From these results it can be concluded that the energy produced from soybean B20 is greater than B20 porang. This is also due to the influence of fuel properties such as flash point and low heating value [16].



(a)

(b)

Figure 7. SFC diagram under condition (a) engine speed 1800 rpm and full load (b) engine speed 2200 rpm and full load

VII. CONCLUSION

Combustion and performance test results can be concluded that kemiri sunan biodiesel has the potential to become renewable energy fuel. This is because of fuel properties from kemiri sunan has meet the standard, although in this research is not perfect result due to error factor of biodiesel making process. However, it has been proved in various indicators, namely combustion test and performance test which show relatively similar results with Pertamina's fuel diesel fuel. This will provide a future recommendation for better development in order to achieve the use of alternative energy for Indonesia.

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